NATIONWIDE FORESTRY APPLICATIONS PROGRAM

operational test of panoramic aerial photography for estimating annual mortality of ponderosa pine caused by mountain pine beetle

USDA Forest Service
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September 1981

OPERATIONAL TEST OF PANORAMIC AERIAL PHOTOGRAPHY FOR ESTIMATING ANNUAL MORTALITY OF PONDEROSA PINE CAUSED BY MOUNTAIN PINE BEETLE

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16. Abstract

This report presents the results and conclusions of an operational test of the procedures used in a mortality survey designed to provide timely data to the Forest Pest Management staff of the U.S. Department of Agriculture, Forest Service. The Front Range of Colorado, an area of approximately 12 million acres, was the study area.

The survey design is based on three-stage sampling with selection according to probability proportional to size. Information from each stage is combined to estimate the number of trees killed and the associated volume loss from mountain pine beetle infestation.

The results show that an estimated 79,898 trees were killed in 1980 with an associated volume loss of 950,199 cubic feet. The relative standard errors are 15.7 and 14.7 percent, respectively.

The operational test demonstrated that, after the photography is collected, high-altitude panoramic photography can be used in a timely manner to satisfy the requirements of the Forest Insect and Disease Information System.

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INTRODUCTION

In recent years, the mountain pine beetle has caused extensive damage to western forests. In 1977, an estimated 1.25 million trees were killed by this insect in the Colorado Front Range alone (ref. 1). Responding to this threat, public agencies and private landowners are currently spending large sums of money to combat the beetle along the Front Range.

For the response to be most effective, all aspects of the beetle host system must be studied and weighed to provide the resource manager with information for decision making. This is known as integrated pest management (IPM). The first part of IPM consists of having both the data and the information systems available for decision making.

Data required for pest management decision making vary with the level of management - local, regional, and national. At any level, the data required must be accurate, timely, and comparable and show current status and trends of major pests.

A Forest Insect and Disease Information System (FIDIS) has been designed to provide a framework for sampling and reporting, on a national basis, the status of major forest pests. It is designed to respond mainly to regional and national data requirements but will be structured to handle in-place information needed at the local level (refs. 2, 3).

For the last several years, two U.S. Department of Agriculture (USDA) groups, the Methods Application Group and the Region 2 Forest Pest Management staff, have been designing and implementing survey systems, on a large-area basis, to estimate the annual tree mortality caused by the bark beetle. These systems generally involved the use of aerial sketch maps to stratify the study area and low-altitude spot aerial photography and a small ground sample to estimate mortality and obtain data on the remaining volume of timber (refs. 4, 5, 6).

These previous survey systems, using large-scale photography, dictated that they be used to sample infestations rather than for 100-percent photographic coverage. The recent availability of high-altitude high-resolution photography may permit the use of smaller scale photography and thus allow more extensive coverage of infested areas (ref. 7). Alternative survey procedures which use high-altitude photography have been developed and tested by the Forest Pest Management staff, the Methods Application Group, and the Nationwide Forestry Applications (NFA) Program (refs. 8, 9).

During 1979, two regional sampling designs, a conventional multistage survey technique (ref. 6) and a multistage sampling design utilizing Itek KA-80A (optical bar) panoramic camera photography, were evaluated along the Front Range in Colorado (ref. 10). Both systems estimated the annual mortality of ponderosa pine caused by mountain pine beetle infestation. The design that used panoramic photography required less aircraft time and no aerial sketch map. It has proven to be a realistic alternative to the conventional technique. In addition, panoramic photography provides the advantage of total area coverage for in-place surveys and the possibility of use by other resource units.

The 1979 Colorado survey was not considered a complete success because weather prevented the entire Front Range from being photographed, photointerpretation problems were identified, and it was not designed to respond to the FIDIS requirements. Therefore, in 1980, the present study was designed as an operational test of panoramic photography for providing ponderosa pine mortality data to the FIDIS.

OBJECTIVE

The objective of this study was to evaluate the use and value of high-altitude panoramic aerial photography

for obtaining FIDIS inputs on the annual mortality of ponderosa pine caused by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins).

FIDIS information requirements (Level II) for an infestation are:

- Acres - acres of ponderosa pine infested by the mountain pine beetle, according to the following ownership classes: national forest, other Federal, state, and private.
- Number - total number of trees killed.
- Volume - volume of timber killed.
- Precision - maximum allowable precision for volume loss, a 20-percent sampling error of the mean at the survey level. Estimates of mortality and volume by ownership class are prorated from the total and have no sampling error.
- Map - a display of the study area showing the distribution of the infestation.
- Timing - the above requirements should be completed by January 15 of the year after the survey.

In addition, data on man-hours expended and associated costs have been provided so that management decisions can be made on the practicability of the panoramic survey system.

PANORAMIC PHOTOGRAPHY

Panoramic Camera

High-altitude panoramic camera features which are particularly attractive to Forest Service users are high-resolution stereoscopic imagery over large areas with a minimum of flight time.

An aerial panoramic camera achieves large-area coverage at high resolution by using only the center of a lens with a narrow field of view and sweeping the lens across the terrain, perpendicular to the line of flight. The effective projection of the ground plane onto the cylindrical film platen by the lens produces a decreasing scale away from nadir. This variation in scale is known as panoramic distortion (ref. 11). That is, scale decreases and obliquity increases outward from nadir (fig. 1).

The Itek KA-80A optical bar camera uses standard 5-inch-wide film to produce 4.5- by 50.26-inch images. The lateral coverage is 120° (60° to each side of nadir). When flown at 60,000 feet above ground level, the camera focal length of 24 inches produces photographs with scales of 1:30,000 at nadir and 1:60,000 at the edge of the frame. The panoramic photography covers a distance of 1.85 nautical miles at nadir and 3.7 nautical miles at the edge of the image. The cross-track coverage is 34.2 nautical miles. The effective working angle is normally ±40° to either side of nadir. This is caused by the decreasing scale, increasing image obliquity, and color attenuation problems at wide viewing angles; i.e., greater than 40°.

The resolution of the image is theoretically constant even though the scale varies as the distance from nadir increases (ref. 11). In an empirical study, the resolution of Itek KA-80A color infrared photography was measured using standard military resolution targets (ref. 12). With a nadir scale of 1:30,000, there was no loss of resolution with increasing distance from nadir. A photointerpreter was able to distinguish objects 2 feet wide at nadir and objects 4 feet wide at the limit of scan (60°).

Equal-Area Grid

The influence of panoramic distortion because of camera characteristics can be reduced by using equal-area grid overlays. Mathematical models and associated computer programs written by the USDA Forest Service Engineering Geometronics Group in Washington, D.C., were used to construct the grids. These programs simulate the panoramic geometric characteristics of the Itek KA-80A optical bar camera. The projective equations required to model

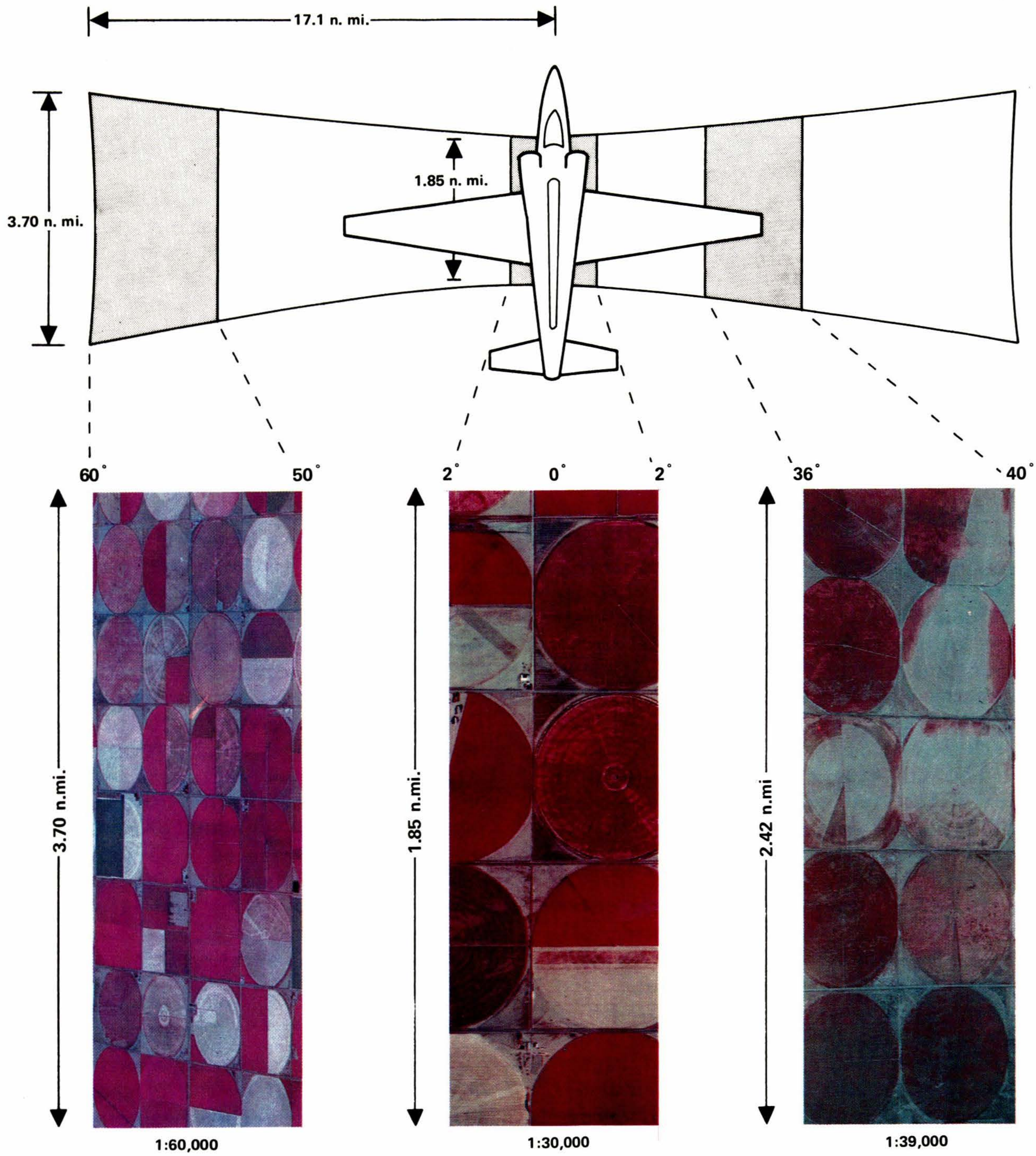

Figure 1.- Area coverage and panoramic distortion of Itek KA-80A photography at 60,000 feet above ground level. Circular irrigation systems are 0.5 mile in diameter.

panoramic photography closely follow the analysis provided in the manual of remote sensing (ref. 11). By using one of these programs, PANGRID (ref. 13), and specifying the grid cell size, grid scale, scan angle limits, and several labeling options, a user can create an image of an equal-area grid on the ground.

For this survey, an equal-area grid of 148 cells was constructed at a nadir scale of 1:30,000. Each cell was 160 acres in size and was arranged in 4 rows of 37 cells each. These cells covered an area 40° to either side of nadir. Each cell was subdivided into 32 subcells of approximately 5 acres each (fig. 2).

SURVEY AREA

The Front Range of Colorado is approximately 12 million acres and includes portions of the Pike, San Isabel, and Rio Grande National Forests. Excluding the North Park area and San Luis Valley, this area includes the Rocky Mountains east of the Continental Divide from the Wyoming state line on the north to the New Mexico state line on the south (fig. 3).

The Colorado Front Range is a complex of forested mountain ranges, mesas, and plateaus interspersed with nontimbered valleys, foothills, and low ranges. Below 5500 feet, vegetation is largely grass or salt-desert shrubs. These cover types blend into sagebrush (*Artemis* sp.), oakbrush (*Quercus gambelii* Nutt.), pinyon pine (*Pinus edulis* Engel.), and juniper (*Juniperus scopulorum* Sarg.) at about 5500 to 6500 feet. Under more favorable moisture conditions at higher elevations, forest stands of commercial timber quality predominate. Ponderosa pine (*Pinus ponderosa* Laws.), Douglas fir [*Pseudotsuga menziesii var glauco* (Beissn.) Franco], aspen (*Populus tremuloides* Michx.), lodgepole pine (*Pinus contorta* Engel.), spruce (*Picea engelmanni* Engel.), and other fir types (*Abies lasiocarpa* Nutt.) appear, in that order, up to the timberline at about 11,500 feet. Because of the extreme climatic and physiographic variations in Colorado, large differences in growing conditions occur which affect tree size and quality, as well as species. These variations in the size, quality, and species of trees occur locally and throughout the state (ref. 14).

The mountain pine beetle appears throughout the ponderosa pine forest of the Front Range and is epidemic over most ponderosa pine types. Other parts of Colorado, where mountain pine beetle infestations are considered endemic, were not surveyed.

METHODS

Photographic Acquisition

A National Aeronautics and Space Administration (NASA) U-2C aircraft (Missions 80-121 and 80-122) collected a total of 1105 frames of Itek KA-80A panoramic photography on August 21 and 22, 1980. The photography was taken at 65,000 feet above absolute mean sea level with a 55-percent forward lap at nadir. The average terrain elevation was assumed to be 5000 feet; thus, with the 24-inch lens, the nadir scale of the photography was 1:30,000. Aerochrome high-definition infrared (SO-131) film was used. Six flight lines covered the study area (fig. 3). Ninety-eight percent of the area was cloud free, and the image quality was excellent.

Indexing

The mission photography consisted of 16 rolls of film after the original film was duplicated. The beginning and ending frames and every fifth frame between were plotted on U.S. Geological Survey (USGS) 1:250,000-scale maps. The nadir point and the lateral coverage of the frames were plotted in order to determine the total extent of photographic coverage, to evaluate the sidelap, and to provide an index of rolls

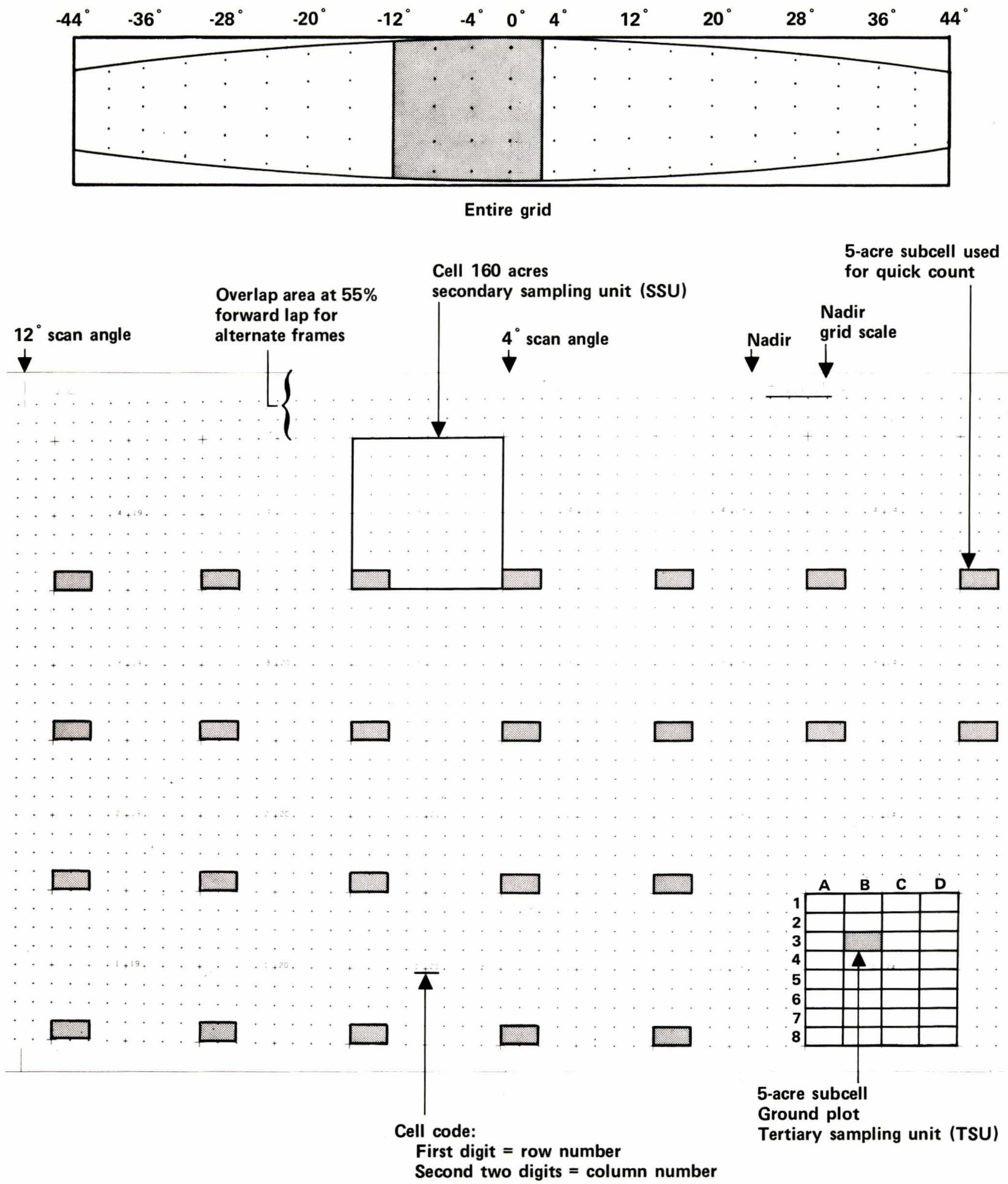

Figure 2.- Central portion of equal-area grid used in the photointerpretation of each frame of photography. (Each frame is a primary sampling unit.)

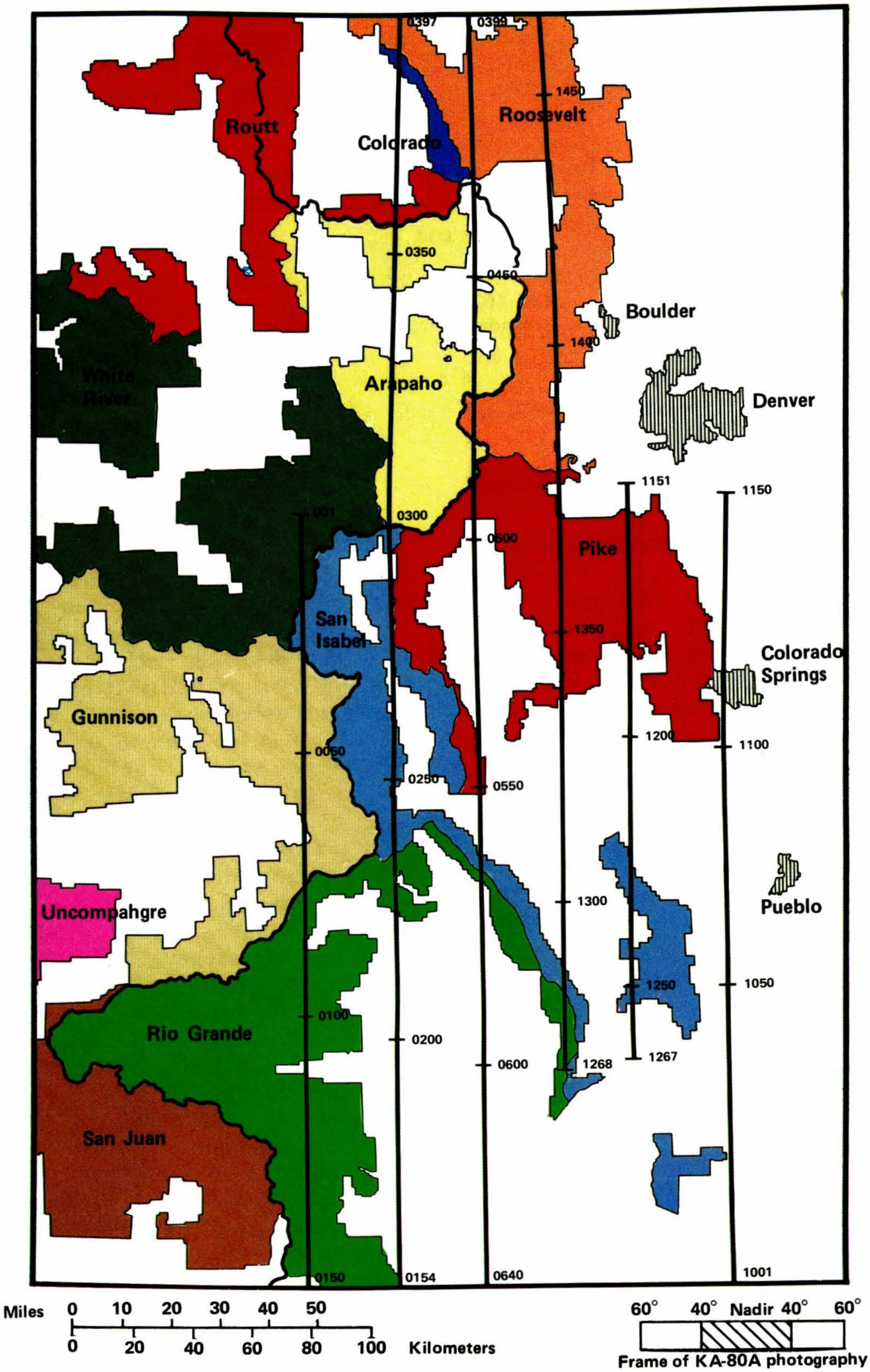

Figure 3.- Colorado Front Range survey area (1980), showing flight lines and selected frame numbers.

versus frame numbers by geographic area. Because of the compressed work schedule, all film was not available for plotting at the beginning of the analysis.

Photointerpretation

Eight photointerpreters were used for this study. Four were experienced with panoramic photography and were familiar with the photographic and ground characteristics of ponderosa pine killed by the mountain pine beetle. The other four were trained foresters or entomologists who had limited photointerpretation experience but extensive experience with mountain pine beetle damage.

All personnel involved in the photointerpretation participated in a 1-1/2 day training session. The photointerpreters used the Richards MIM-4 light table with Bausch & Lomb zoom 240 heads to view and analyze the photography. Viewing was usually at 10x to 14x magnification. The interpretation was made in a monoscopic mode for the quick count and the detailed count. The count of the 160-acre cell was made in the stereoscopic mode.

Survey Design

The survey design was based on three-stage sampling with selection according to probability proportional to size (PPS) at each stage (fig. 4). Information from each stage was combined to estimate the number of faders[1] and total volume (appendix A). These stages entailed (1) a quick count of the number of faders in each panoramic photographic frame and selection of sample frames, (2) careful photointerpretation of the 160-acre cells of selected frames and selection of sample cells, (3) detailed photointerpretation of the 5-acre subcells of selected cells and selection of sample subcells (ground plots). Ground-truth collection was then accomplished by visits of three-man crews to the selected ground plots.

In the first stage of the design, a quick count of the number of faders was recorded for each of the 552 photographic frames. The frames are referred to as primary sampling units (PSU's). The quick count for a frame was obtained by summing the fader counts from each of the 5-acre subcells located in the lower left-hand corner of all 160-acre cells in that frame. The photointerpreter placed an equal-area grid over every even-numbered frame in the roll of film for this count (fig. 5). Based on the fader counts per frame, 80 frames were selected by PPS for further evaluation. Since selection was made with replacement, some frames were selected more than once.

The 80 selected frames and the associated stereoframes were cut from the rolls of film and laminated to avoid damage to the film during later photointerpretation. One equal-area grid was attached to each frame of photography.

In the second stage, each of the 80 selected frames (PSU's) was divided into 148 cells (160 acres each). These 160-acre cells are the secondary sampling units (SSU's). On each selected frame, a careful count of faders from the photographs was recorded for each of the 148 cells, and 1 cell was chosen with probability of selection proportional to the fader counts. Frames chosen more than once were counted by a different photointerpreter each time (fig. 6).

In the third stage, each of the selected 80 cells (SSU's) was divided further into 32 subcells (5 acres each). Each subcell, called a tertiary sampling unit (TSU), was carefully interpreted stereoscopically for the number of faders; and one subcell was chosen with probability proportional to those detailed counts (fig. 7).

Seventy-eight 5-acre plots were selected for ground examination (fig. 8). During the stereoscopic examination of

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[1] "Fader" is a colloquial term for a ponderosa pine tree having a discolored (yellow/orange) appearance which results from attack by the mountain pine beetle.

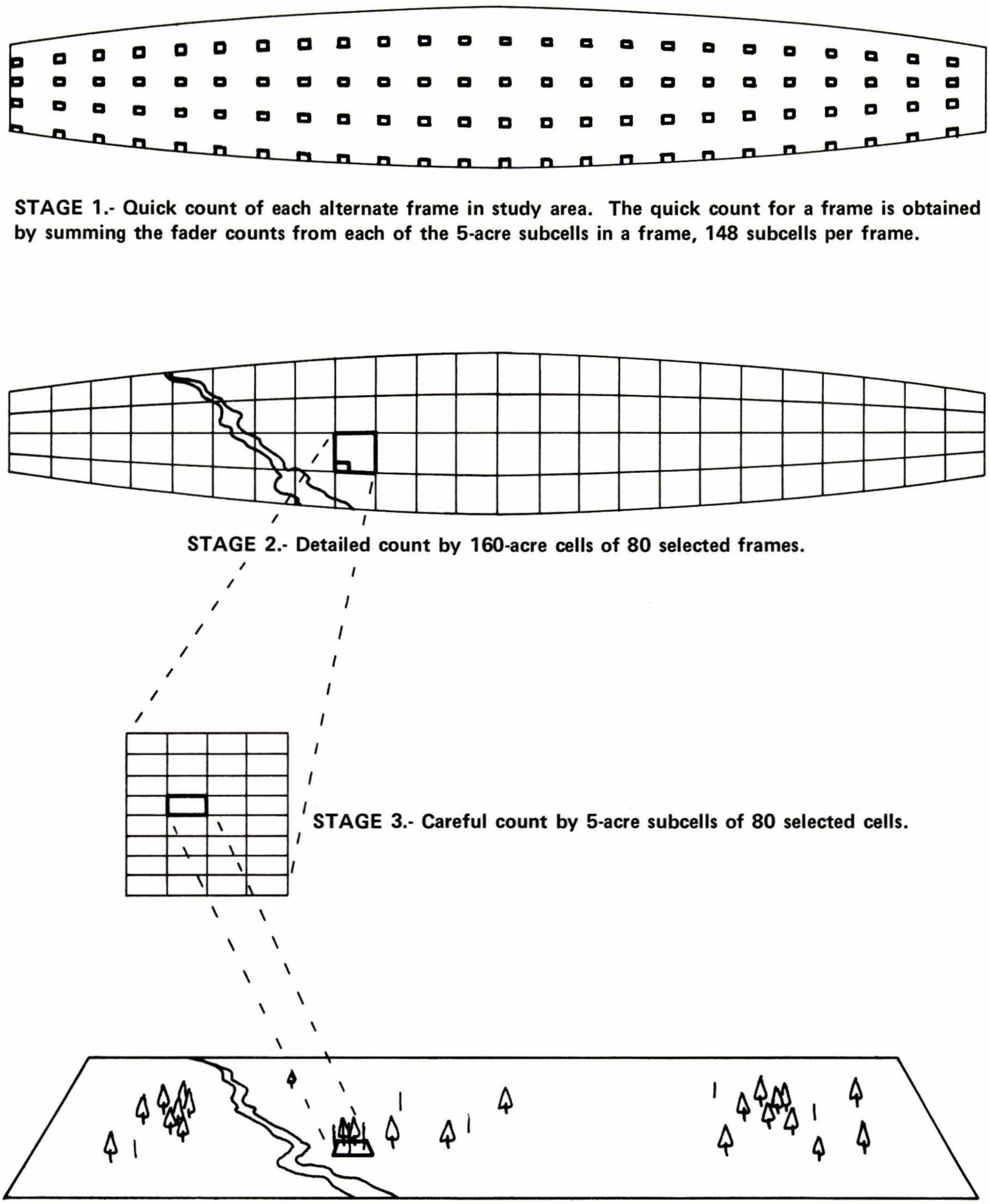


Figure 4.- Survey design based on three-stage sampling used for the 1980 Colorado Front Range survey.

Figure 5.- The quick count of faders was made using the Richards MIM-4 light table and the Bausch & Lomb zoom 240 heads.

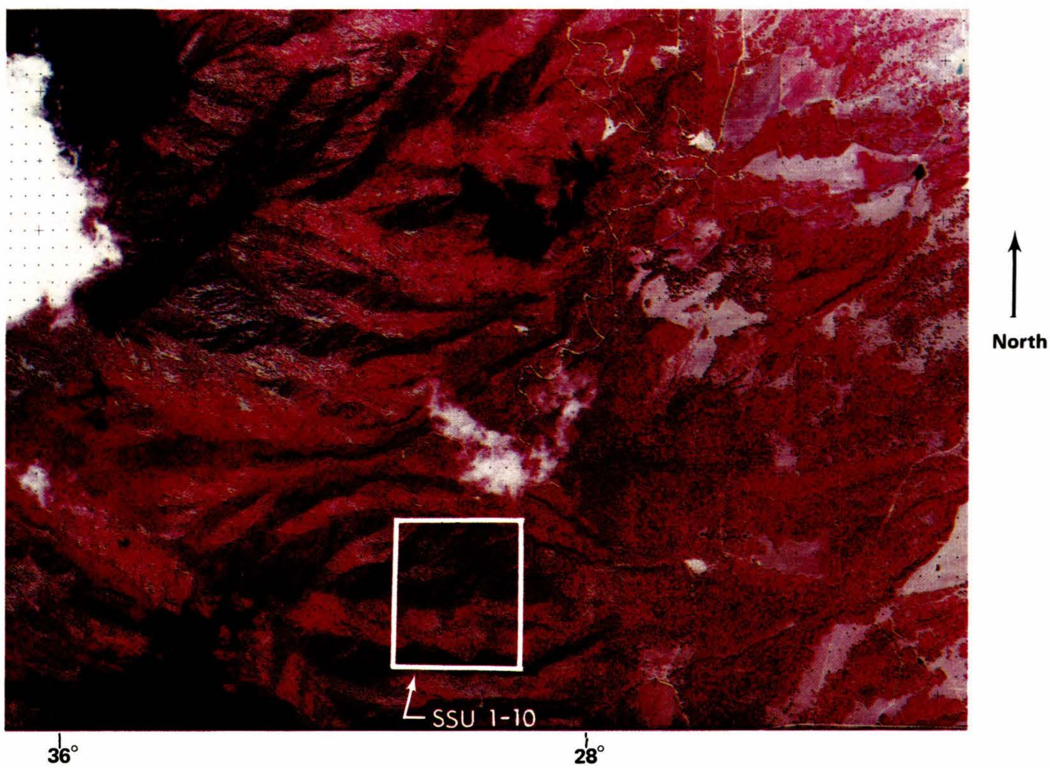


Figure 6.- Portion of KA-80A panoramic photograph centered at 28° with equal-area grid superimposed (NASA Mission 80-122, frame 1052, scale: 1:35,000). The equal-area grid is used for all stages of the photointerpretation.

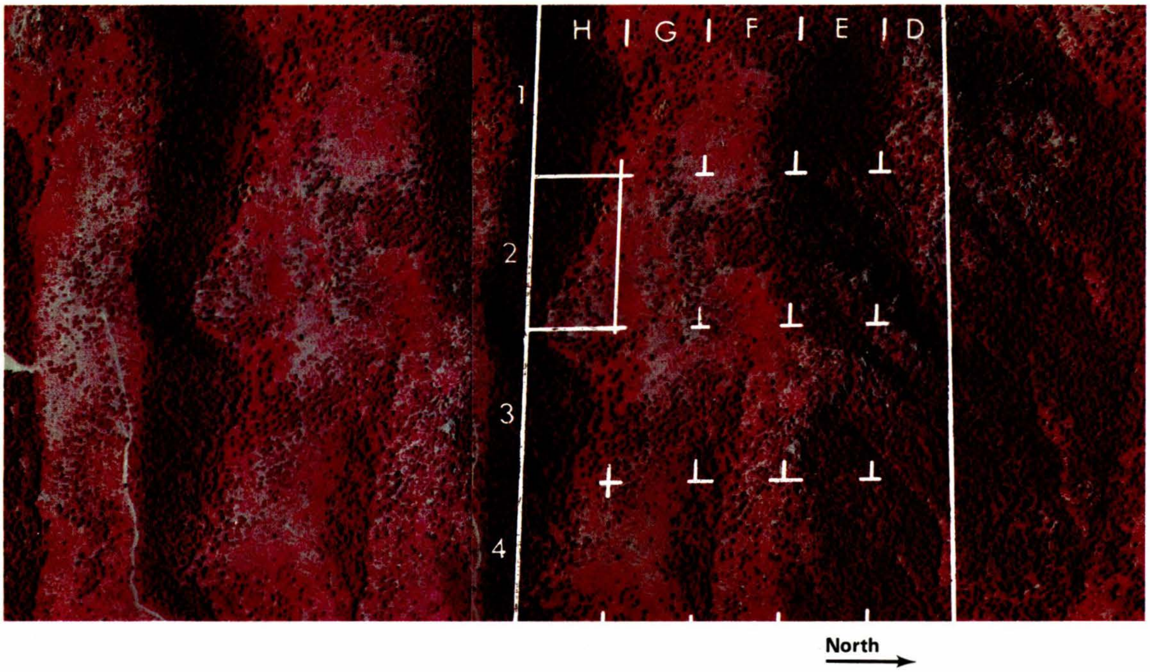


Figure 7.- Stereogram of enlarged portion of high-altitude panoramic photographs (NASA Mission 80-122, frame 1052, SSU 1-10, scale: 1:7500). Stereoscopic viewing of 5-acre cells is used in stage 3 of the photointerpretation.

Figure 8.- Ground photograph of ponderosa pine faders (1980) for plot 1052-1-10-H2. TSU H2 was selected from the SSU 1-10 shown in figure 7.

the photography, two plots were found to contain no faders. These plots were assigned a zero count and were not visited in the field.

Using field stereoscopic viewers, three-man crews located the plot corners and marked the plot boundaries. Then, all current-year faders within the plot were tabulated by DBH class. The heights of three trees in each DBH class were measured for volume determination; where possible, the 1st, 6th, and 11th trees encountered in each DBH class were measured.

Display

The display of the study area showing the distribution of the infestation was developed using the stage 1 quick-count data. The quick-count sample of each even-numbered frame of photography was digitized and displayed with a one-to-one aspect ratio. The scale of the display was adjusted photographically and overlaid onto Bureau of Land Management (BLM) ownership maps at a scale of 1:126,720. In addition to the number of current-year faders, the following classes were indicated for each 5-acre subcell:

- Nonforest - if 90 percent of the cell was covered by vegetation other than pinyon pine, juniper, or other commercial timber species; i.e., pasture and oakbrush.
- Clouds or cloud shadows - if 60 percent of the cell was obscured by clouds or cloud shadows.
- Water - if 50 percent of cell was covered by water.

RESULTS

Number of Trees and Related Volume

The estimated total number of faders was 79,898 from 11,187,680 acres surveyed. The associated volume was 950,199 cubic feet. The relative sampling errors were 15.7 and 14.7 percent for the number and volume of faders, respectively. The statistical formulas and ground data used to develop this estimate are given in appendixes A (ref. 15) and B.

The above estimate does not include trees obscured by clouds or removed before the date of the photographic acquisition. Clouds obscured 129,120 acres within the study area, mainly in the Pike and San Isabel National Forests. This area had high losses in 1979 and was expected to have high mortality in 1980. An independent survey consisting of aerial sketch mapping and ground verification was conducted for the cloud-covered area to calculate an estimate of loss (ref. 16). This survey estimated a loss of 2234 trees with a standard error of 12.8 percent. An additional 43,000 trees were estimated by the State of Colorado to have been removed in the course of prevention and suppression activity before the survey. The total loss was, therefore, about 125,132 trees (ref. 17).

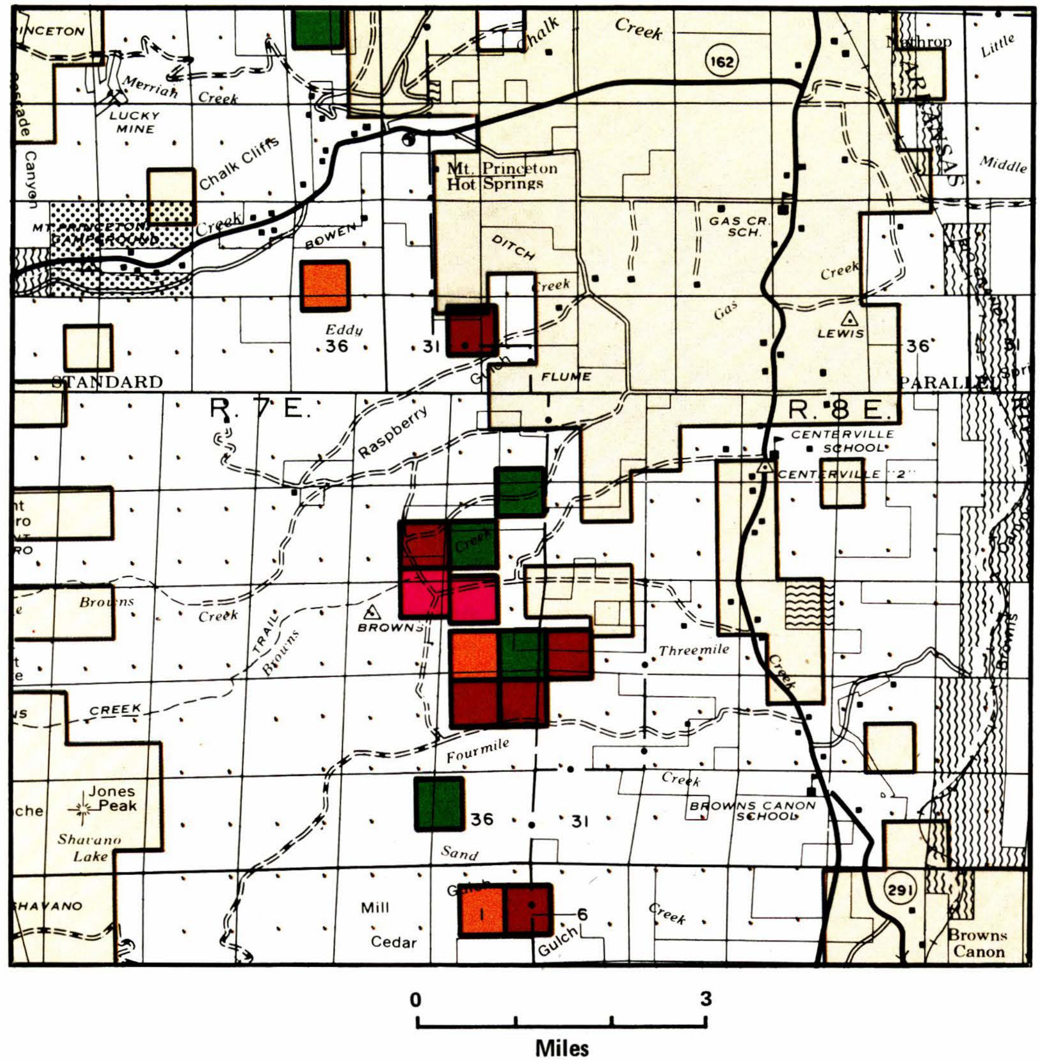
Display

A portion of the display showing the distribution of the infestation is shown in figure 9. This display has been matched to a BLM 1:126,720 scale ownership map. The infestation display and BLM ownership map together were used to estimate the proportion of infested areas which fell in a given ownership class. These proportions were then used to prorate the number and volume loss by ownership for the study area (table 1). These estimates were made available to the Forest Service by January 15, 1981.

DISCUSSION

FIDIS Requirements

The standard error of the estimate for both the number of faders and volumes is below the FIDIS Level II



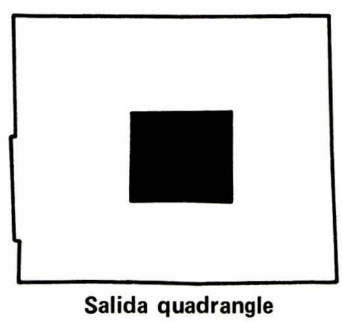


Figure 9.- Display of ponderosa pine mortality for a portion of the BLM Salida quadrangle.

TABLE 1.- OWNERSHIP CLASSIFICATION OF PONDEROSA PINE MORTALITY CAUSED BY THE MOUNTAIN PINE BEETLE IN THE FRONT RANGE OF COLORADO, 1980

Class	Acres infested	Ownership, %	Number of faders	Standard error, %	Volume estimate, cu ft	Standard error, %
National Forest	30 516	48	38 192		454 196	
Other Federal	10 980	17	13 742		163 434	
State	1 851	3	2 317		27 555	
Private	20 493	32	25 647		305 014	
Total	63 840	100	79 898	±15.7	950 199	±14.7

requirements. A measure of the accuracy of these results is achieved by comparing them to a prediction of the 1980 losses developed during the 1979 conventional survey (ref. 6). The predicted loss in 1980 was 92,000 trees. This agrees favorably with the 1980 high-altitude panoramic survey results when cloud cover estimates and some tree removals before the survey are included. The State of Colorado estimated that 43,000 ponderosa pines were removed before the survey. This estimate is statewide, and its applicability to the Front Range study is uncertain.

The displays of the mortality developed from the quick counts are being evaluated for their utility. The positional accuracy is estimated to be about ±1 mile. This estimate is based on a comparison of control points on the BLM Salida map sheet and the quick-count display.

Cost

This survey required 4123 hours at an estimated cost of $108,252 (table 2). The major cost in both hours and dollars was for the field work. Field work required 66 percent (2720) of the total hours and 48 percent ($51,486) of the total estimated dollars. Photointerpretation required the next largest number of hours (913 or 22 percent of the total). Photographic acquisition was the second ranking cost, representing 37 percent of the total.

The total hours required to complete the high-altitude Colorado Front Range survey decreased by about 12 percent from 1979 (4700 hours) to 1980 (4100 hours). This decrease occurred even though the survey included 7 million more acres and required an estimate of volume and a display of mortality. The decrease in hours was attributed to the experience gained in the previous surveys by using the proven 1979 survey procedures. The hours per frame for photointerpretation and the total hours for field work were about the same for both years.

The photographic acquisition cost represents about 37 percent ($39,930) of the survey costs. This cost is quite high when compared to the cost of data acquisition for the conventional survey.

TABLE 2.- DIRECT LABOR HOURS AND REPRESENTATIVE PROJECT COSTS FOR THE 1980 COLORADO FRONT RANGE SURVEY

Item		Hours	Cost (a)
Photographic acquisition[b]		[c](2.9)	$ 39 930
Management		30	360
Experiment design		40	480
Index film		20	240
Photointerpretation			
Training	80		
Quick count (552 frames × 0.30 hr)	166		
PSU count (80 frames × 8 hr)	640		
SSU count (80 SSU's × 0.34 hr)	27		
Total photointerpretation		913	10 956
Field data collection			
Subsistence ($18,846 + 2720 hr @ $12)		2720	51 486
Survey estimates		80	960
Development of mortality display		160	1 920
Documentation		160	1 920
Total		4123	$108 252

[a] Labor calculated at $12/hour.

[b] Photographic coverage for 11.188 million acres; $0.0036/acre or $2.288/square mile.

[c] Data collection hours.

However, it is noteworthy that 100 percent stereocoverage was acquired over approximately 12 million acres in 2 days. This represents total current photographic coverage of the Roosevelt, Pike, and San Isabel National Forests; the Rocky Mountain National Park; and the Florissant Fossil Beds and Great Sand Dunes National Monuments. Partial photographic coverage is available for the Routt, White River, Gunnison, and Rio Grande National Forests. The panoramic photography has already demonstrated its usefulness in areas other than insect damage surveys. Studies have been completed which describe the utility of panoramic photography for midcycle updates of large-area timber volume estimates (ref. 18), timber typing on the forest level (ref. 19), map update (ref. 20), and timber damage assessment (ref. 21). The use of the photography for in-place mapping of mountain pine beetle damage is currently being investigated (ref. 22). Even though the initial cost of photographic acquisition is high, its use for other projects and by other agencies can make its use cost effective.

Data Acquisition

Problems in coordinating the data acquisition in 1980 were due primarily to the volcanic eruption of Mount St. Helens. The U-2C which was scheduled to fly over Colorado was required to fly about 10 missions over the Mount St. Helens disaster area from May 20 to July 15. Thus, during the optimal biological window for collection of the Colorado photography (end of July), the aircraft was undergoing required maintenance. Therefore, the Colorado photography was not collected until August 21 and 22, 1980. This delay created a compressed time schedule which, as occurred in 1979, created the following problems:

- The number of days with acceptable cloud cover was reduced.
- The time available for photointerpretation and field work was reduced.
- The chances of commission errors by photointerpreters increased because the 1979 faders looked more like 1978 faders.
- The problem of identifying current-year faders by ground check was increased.

The compressed schedule required that film duplication, film indexing, and photointerpretation be conducted in parallel. Thus, it was not until the end of the quick-count stage that several holiday and overlap areas caused by the equal-area grids were identified. At that stage, it was too late to effectively adjust the areas of photographic interpretation.

The holidays and overlap areas were also noted and illustrated by Klein (ref. 8). The variation in forward overlap causes some areas to be excluded from the target population and some areas to be sampled twice. Map-registered grids can be used to ensure that the sample population coincides with the target population. The cost and time required to construct map-registered grids increase the total survey cost considerably. The equal-area grids are more economical. When these grids are used the coverage of each photograph should be plotted to ensure the entire target population is covered.

Photointerpretation

Photointerpretation errors of commission were reduced from 16.3 percent in 1979 to 12.5 percent in the 1980 survey. This reduction in commission error was attributed to the experience gained by the interpreters in the 1979 survey. The interpreters' efforts to identify trees with marginal ponderosa pine fader signatures were the primary cause of the 1980 errors. The majority of the misidentified plots in 1980

contained lodgepole pine or white pine faders. Stereoscopic viewing resulted in the discovery of two plots with no faders (table 3). The use of an improved resolution imaging system (the IRIS II) may reduce the misidentification by providing better color contrast and crown detail.

The last problem, misidentification of current-year faders on the ground, was addressed in a separate study (ref. 23). Plots containing current faders were located, and the trees were tallied in early July while the beetles were still in the trees. This ensured positive identification of the 1980 faders for these selected plots. These fader plots were revisited in October by the regular ground-truth teams, and the current-year faders were tallied a second time. The two tallies were then compared to determine the significance of any differences between the counts. The results showed that, statistically, there was no difference in the number of current-year faders counted on the ground in July versus the number counted in October. This indicates that collecting field data as close as possible to the date of photography is not as critical in Colorado ponderosa pine surveys as was previously believed. The weather is a more limiting factor, inasmuch as bad weather will limit travel for ground data collection and will begin to physically alter the characteristics of current-year faders.

Interpretation Versus Scan Angle

No difference was found in the detection accuracy with distance from nadir. Two previous studies showed a statistical difference between counts at less than 20° and greater than 20°. Such a variation was attributed to increasing obliquity and color shifts away from nadir.

For the 1980 survey data, an analysis was performed to determine if a change in detection accuracy occurred with increasing distances from nadir. The 80 plots were divided into two groups: one group with plots falling between nadir and ±20°, and the other with plots falling outside that range (±20° to ±40°). The correlation coefficients r between the ground counts and the TSU counts were calculated for both groups, and a test of the significance of the difference

TABLE 3.- SUMMARY OF PHOTOINTERPRETATION COMMISSION ERRORS FOR 2 YEARS OF COLORADO PEST SURVEYS USING PANORAMIC PHOTOGRAPHY

[Eighty plots checked on the ground]

Ground-truth category	Plots with faders as identified by photointerpretation	
	1979, monoscopic viewing	1980, stereoscopic viewing
Faders (lodgepole pine, white pine)	2	6
No faders (rock, bare soil, grass)	11	2
No faders by stereoscopic viewing	0	2
Total number of plots with no ponderosa pine faders	13	10

between the two correlations was made using Fisher's transformation z as shown in table 4(a). With probability $P = 0.45$ (the two-sided test), there seemed to be no significant difference between the z's and hence no significant difference between the two correlation coefficients.

The same test was performed on the 1979 survey data, and the results are given in table 4(b). With $P = 0.0375$ (the one-sided test), it was concluded that the correlation coefficients are significantly different for the two groups and that the correlation coefficient between the ground counts and TSU counts is higher when the scan angle is below 20°.

This difference between the results from the two surveys may be attributed to the use of stereoscopic viewing for the stage 3 count in the 1980 survey.

CONCLUSIONS

The FIDIS data requirements can be met in a timely manner with high-altitude panoramic photography. The number, volume, and acreage of ponderosa pine killed by the mountain pine beetle were estimated by ownership classes with less than 15 percent standard error. Useful displays of the mortality distribution were produced for approximately 12 million acres from a systematic sampling of the panoramic photography.

The cost and scheduling of the panoramic photography continue to be problems for the survey. Costs for pest coverage surveys can be reduced by sharing the acquisition cost with other potential users, such as timber management or state agencies. Scheduling of the NASA aircraft is a continuing concern to all those involved with high-altitude photographic acquisition. Even prior scheduling and more aircraft availability cannot guarantee timely coverage if a higher priority event occurs; i.e., the volcanic eruption of Mount St. Helens.

The overall survey procedures are efficient and produced precise results. The 5-acre ground plots are of satisfactory size for ground data collection in ponderosa pine stands, and three men on the ground crew is an optimal number. Finally, the photointerpretation commission error is improving but remains at about 12 percent.

RECOMMENDATIONS

The following suggested studies and procedural changes are needed to improve the accuracy and efficiency of large-area pest damage surveys.

- Close coordination should be maintained with the flight crews and the survey project leader to ensure that flight specifications are followed, that critical areas are flown first, and that the film can be previewed at the aircraft facility so that cloud-covered areas can be reflown immediately.
- All film should be available for indexing before photointerpretation begins. This will allow for adjustment of the equal-area grids to ensure that all ground areas have a probability of being selected.
- Studies with the improved resolution IRIS II and IRIS III panoramic camera systems should be conducted to determine if they can reduce the photointerpretation commission error and improve survey precision and efficiency.
- If it is required that displays of mortality with more positional accuracy then the ±1 mile be produced, computer programs should be developed to register the quick-count data to map sheets.

TABLE 4.- TEST OF SIGNIFICANCE OF THE DIFFERENCE BETWEEN TWO CORRELATIONS OF GROUND COUNTS WITH TSU COUNTS

(a) 1980 Survey

Group	Scan angle	Number of plots, n	r	z	$\frac{1}{n-3}$
1	≤20°	49	0.8683	1.32613	0.02174
2	>20°	31	.9063	1.50641	.03571
				Difference = -0.18028	Sum = 0.05745

$$\sigma_{z_1-z_2} = \sqrt{0.05745} = 0.23969$$

$$\frac{z_1-z_2}{\sigma_{z_1-z_2}} = \frac{-0.18028}{0.23969} = -0.75214$$

P = 0.45

(b) 1979 Survey

Group	Scan angle	Number of plots, n	r	z	$\frac{1}{n-3}$
1	≤20°	60	0.8918	1.43065	0.01754
2	>20°	20	.7349	.93930	.05882
				Difference = 0.49135	Sum = 0.07636

$$\sigma_{z_1-z_2} = \sqrt{0.07636} = 0.27633$$

$$\frac{z_1-z_2}{\sigma_{z_1-z_2}} = \frac{0.49135}{0.27633} = 1.7781$$

P = 0.0375

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APPENDIX A

STATISTICAL ANALYSIS

Stereoscopic examination of the photographs disclosed that 2 plots of the original 80 contained no faders. Ground truth data were collected on 78 selected 5-acre plots (TSU's). Because harvest had occurred on 2 of the 78 ground plots, regression estimates of the ground counts for these 2 plots were obtained by regressing the ground counts (y) onto the TSU counts (x), based on the remaining 76 sets of data (appendix B). The regression line is given by

$$y = 1.819x - 3.285 \tag{1}$$

where y = faders on the ground and x = faders of TSU's on the Itek KA-80A photography.

The correlation coefficient r between the ground counts and TSU counts is 0.875.

The photographic counts at different stages and the ground counts (two of which were estimated through the above-mentioned regression line) were then inserted into equations (3) and (4) to obtain an estimate of the total number of faders in the study area and its standard error.

To estimate the total volume of faders in the study area, the volume for each of the 80 ground plots was estimated first. The estimate of the volume of faders in a ground plot was calculated using the average height and DBH of various DBH classes. The estimate X_{ijk} of the volume in the kth TSU of the jth SSU of the ith PSU is

$$X_{ijk} = \sum_{\ell=5}^{26} V_\ell S_{ijk\ell} \tag{2}$$

where

$S_{ijk\ell}$ = the number of faders in the kth TSU of the jth SSU of the ith PSU and in DBH class ℓ

V_ℓ = the estimated volume of a single tree in DBH class ℓ

$= 0.001824\, D_\ell^2\bar{H}_\ell + 0.5870$ if $D_\ell^2\bar{H}_\ell \leq 6000$

$= 0.002103\, D_\ell^2\bar{H}_\ell - 1.091458$ if $D_\ell^2\bar{H}_\ell > 6000$

D_ℓ = the DBH for class ℓ

$\bar{H}_\ell$ = the average height of all faders measured in DBH class ℓ

The estimated volumes of all 80 ground plots were then inserted into equations (3) and (4) to obtain an estimate of the total volume of faded trees in the study area and its standard error.

The following formula was used to calculate the estimate of total faders or volume (appendix C).

$$\hat{X} = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{p_i m_i} \sum_{j=1}^{m_i} \frac{1}{p_{ij} t_{ij}} \sum_{k=1}^{t_{ij}} \frac{X_{ijk}}{p_{ijk}} \tag{3}$$

where

n = the number of PSU's selected in the first stage (= 80)

m_i = the number of SSU's selected from the ith PSU (= 1)

t_{ij} = the number of TSU's selected from the jth SSU of the ith PSU (=1)

X_{ijk} = the number of faders or estimated volume in the kth TSU of the jth SSU of the ith PSU

p_i = the probability of selecting the ith PSU

$$= \frac{q_i}{\sum_{i=1}^{N} q_i}$$

N = the total number of nonoverlapping frames with faders (= 552)

q_i = the sample count of faders in the ith PSU

p_{ij} = the conditional probability of selecting the jth SSU given the ith PSU

$$= \frac{e_{ij}}{\sum_{j=1}^{M_i} e_{ij}}$$

M_i = the total number of SSU's in the ith PSU (= 148)

e_{ij} = the photointerpretation of the jth SSU of the ith PSU

p_{ijk} = the conditional probability of selecting the kth TSU in the jth SSU in the ith PSU

$$= \frac{d_{ijk}}{\sum_{k=1}^{T_{ij}} d_{ijk}}$$

T_{ij} = the total number of TSU's in the jth SSU of the ith PSU (= 32)

d_{ijk} = the photointerpretation of the kth TSU of the jth SSU of the ith PSU

The unbiased estimate of the variance of $\hat{X}$ is

$$S^2_{\hat{X}} = \frac{1}{n(n-1)} \left[\sum_{i=1}^{n} \left(\frac{1}{p_i m_i} \sum_{j=1}^{m_i} \frac{1}{p_{ij} t_{ij}} \sum_{k=1}^{t_{ij}} \frac{X_{ijk}}{p_{ijk}} \right)^2 - n\hat{X}^2 \right] \tag{4}$$

The photographic counts at all three stages, the ground counts, and volume estimates are given in appendix C.

APPENDIX B

ALTERNATE METHOD OF OBTAINING REGRESSION ESTIMATE OF GROUND COUNTS

In the ponderosa pine mortality surveys, ground counts of certain plots were not available because those plots were inaccessible or harvesting had occurred. Regression estimates of the missing ground counts were made using the available ground count as the dependent variable and the TSU count as the independent variable; that is, the ground count was regressed onto the TSU count. The TSU count of the inaccessible or harvested plots was then inserted into the regression line to obtain the estimate of the ground counts. Normally, this relationship is plotted in forest surveys. However, because ground counts are more precise than photographic counts and it is desirable to minimize the deviation which represents photointerpretation error, it seems more appropriate to use the ground count as the independent variable and the TSU count as the dependent variable; that is, to regress the TSU count onto the ground count. Then the inverse of the relation can be used to estimate the ground count. This inverse regression is sometimes called calibration regression.

Statistical methods are often illustrated with fine examples without adequately emphasizing the abstract ideas that underlie the methods; that is, ideas essential to correct statistical thinking. The result is that certain problems with similar objectives appear amenable to identical statistical solutions when, in fact, intrinsic differences exist which considerably alter the details of their solutions. It is often the case that the practitioner is interested in assessing the value of some quantity which is impracticable to assess or impossible to observe directly in a given instance, the estimation being performed with the aid of a relationship between the quantity whose value is sought and another whose value can be determined directly. The curve-fitting procedure usually adopted depends on the additional assumption that the values of the independent variables are known exactly (without error) — an assumption often passed by without emphasis. This simplification of problems without explicit mention of the facts fosters misconceptions that are carried over into the analysis of data. A particularly bad misconception occurs when the variable whose value is to be estimated automatically assumes the role of the dependent variable. The calculation and use of dosage-response curves to estimate dosage constitutes an example. Although it is the amount of dosage we wish to estimate for a given response level, the dosage-response curve should nevertheless be evaluated from a series of observations, with response as the dependent variable. The reason is that measurements of response are subject to various types of error and are relatively imprecise and, therefore, should not be used as independent variables, whereas the amounts of dosage are controlled (exact).

To illustrate the aforementioned in more detail, assume that a linear relationship prevails between U and V.

$$\alpha_0 + \alpha_1 U + \alpha_2 V = 0 \qquad (5)$$

which may be written in the equivalent form

$$V = \alpha + \beta U \tag{6}$$

where

$\alpha = -\alpha_0/\alpha_2$

$\beta = -\alpha_1/\alpha_2$

or

$$U = \gamma + \delta V \tag{7}$$

where

$\gamma = -\alpha_2/\alpha_1$

$\delta = -\alpha_0/\alpha_1$

A common impression regarding the principles of curve-fitting seems to be: If one is interested in estimating V from U, then take $\hat{V} = a + bU$ as the estimate of equation (6); if one were fitting by the method of least squares, the a and b that minimize $\sum(V_i - \hat{V}_i)^2$ would be found. On the other hand, if one is interested in estimating U from V, then $\hat{U} = c + dV$ is to be fitted, the values of c and d being chosen to make $\hat{U}$ a good fit in terms of the deviations $(U_i - \hat{U}_i)$. It does not seem to be generally realized that the fitting should be done in terms of the deviations which actually represent error. Thus, when the U-values can be measured with high precision (or the U-values are selected in advance and held to those values without error), and the researcher then observes the corresponding V-values, the errors are in the V-values. So, even if the researcher is interested in using observed values V_0 of V to estimate U, he should nevertheless fit $V = a + bU$ to minimize the error $\sum(V_i - \hat{V}_i)^2$ and then use the inverse of this relation to estimate U; i.e., $\hat{U} = (V_0 - a)/b$.

This procedure is applicable to the ponderosa pine mortality survey, in which V will be used to estimate U. Because the ground counts are more precise and the photographic counts, which depend on photointerpretation, can be regarded as chance events, the fit $V = a + bU$ and the inverse relation should be used to estimate U.

APPENDIX C

SUMMARY OF GROUND COUNTS AND PHOTOGRAPHIC COUNTS FOR THREE STAGES OF THE 1980 COLORADO FRONT RANGE SURVEY

Table C-1 is a summary of the photographic counts for stages 1, 2, and 3 and the ground counts of the Colorado Front Range Survey. Figures C-1 and C-2 show these data graphically. The total number of faders from the quick count of all 552 frames was 2042.

TABLE C-1.- SUMMARY OF PHOTOGRAPHIC AND GROUND COUNTS

Photographic survey									Ground survey	
Stage 1			Stage 2			Stage 3				
Selected PSU number	Count	Quick counts	Total faders per PSU	Selected SSU number	Faders in selected SSU	Total faders per SSU	Selected TSU number	Faders in selected TSU	Ground counts	Volume, cu ft
140	1	1	28	3-21	19	0	-	-	-	0*
240	1	16	2	3-24	1	2	E-1	1	0	0
	2		3	3-28	2	3	A-1	2	4	32.902
	3		28	1-22	6	11	D-1	8	0	0
	4		9	2-24	4	5	E-2	1	1	28.221
250	1	13	520	4-22	55	44	D-1	20	32	293.319
254	1	35	793	2-25	97	245	B-1	57	97	1133.378
	2		795	4-25	222	590	A-2	22	21	412.171
	3		1179	4-25	363	533	D-1	25	51	633.822
256	1	69	1025	2-24	156	253	E-3	19	27[†]	372.11[†]
	2		1607	1-24	408	590	B-1	58	69	1130.868
262	1	16	165	2-22	17	47	B-1	21	40	284.920
332	1	35	157	2-20	42	25	D-1	3	0	0
366	1	7	56	2-28	39	3	B-3	3	0	0
	2		168	3-27	20	0	-	-	-	0*
456	1	12	214	4-21	25	24	H-3	13	0	- 0
558	1	20	200	4-37	55	49	C-1	39	86	1524.808
564	1	17	450	1-38	103	161	D-3	48	103	2037.999
566	1	35	153	3-32	37	32	H-2	3	0	0
1052	1	34	94	1-10	31	47	H-2	6	6	167.039
1058	1	40	1084	1-6	33	42	C-2	22	66	354.980
	2		1689	2-5	90	54	G-4	33	119	1120.961
	3		1680	3-12	124	145	A-2	69	96	801.698
1100	1	11	46	3-16	9	10	B-4	8	7	109.371
1104	1	15	59	4-14	13	10	C-2	6	6	59.776
1122	1	5	26	3-34	8	4	B-2	3	0	0
1128	1	14	38	3-37	29	39	E-3	21	51	693.864
1152	1	45	985	3-22	53	66	H-4	26	40	192.632
	2		709	4-13	77	117	D-1	17	27	309.545
	3		807	4-18	30	37	A-1	36	34	641.136
1154	1	34	642	1-18	57	45	D-4	33	31	267.938
1156	1	31	839	4-11	77	87	B-4	13	29	409.337
	2		988	3-20	161	158	H-3	18	19	233.906
1162	1	30	1048	4-21	202	236	F-1	25	25	178.453
	2		1701	3-14	80	117	D-1	9	8	119.800
1164	1	13	505	3-31	128	136	A-3	36	47	825.625
1174	1	9	33	4-10	11	21	F-2	8	13	89.934
1198	1	13	89	4-18	18	20	B-2	2	3	36.138
1210	1	48	138	4-28	25	28	G-1	11	0	0
	2		66	3-26	7	6	C-4	3	3	57.807
	3		116	2-28	33	29	C-3	2	2	35.834
	4		125	3-27	7	27	C-1	9	12	192.364
1228	1	9	381	4-16	162	250	E-1	92	163	809.612
	2		467	1-22	21	16	H-2	2	4	49.882
1230	1	47	1020	2-21	158	287	E-3	35	64	876.797
	2		1109	2-21	172	255	B-3	18	20	608.294
1236	1	76	217	1-37	77	132	B-2	39	64	1262.017
	2		210	1-37	65	130	G-3	2	1	65.883
	3		155	2-9	14	17	A-2	13	12	216.315
	4		104	3-10	24	42	E-2	12	15	272.028
1242	1	33	555	2-40	73	180	D-3	2	8	186.278
	2		656	1-36	73	113	H-1	6	8	244.543

*No faders based on stereoscopic examination of SSU.

[†] Indicates regression estimate of the ground count (estimate made between photographic acquisition and ground visit).

TABLE C-1.- Concluded.

Photographic survey									Ground survey	
Stage 1			Stage 2			Stage 3				
Selected PSU number	Count	Quick counts	Total faders per PSU	Selected SSU number	Faders in selected SSU	Total faders per SSU	Selected TSU number	Faders in selected TSU	Ground counts	Volume, cu ft
1246	1	12	128	2-41	27	70	A-2	38	84	709.395
1248	1	5	90	4-40	8	3	G-1	3	4	81.889
	2		60	3-25	26	25	D-1	10	10	711.810
1266	1	28	33	2-14	12	26	C-2	13	22	296.515
	2		11	2-19	9	11	C-2	10	12	247.637
	3		37	2-19	6	9	C-2	8	12	247.637
1292	1	13	196	4-16	85	112	C-2	12	20	248.819
1312	1	16	212	4-26	61	74	H-2	38	160	1496.802
1318	1	32	292	1-10	74	163	C-3	20	29	464.152
1320	1	22	275	1-22	52	100	C-2	29	28	321.584
1328	1	32	234	4-16	50	78	E-1	10	15	296.251
1330	1	30	311	3-22	21	37	A-4	23	23	276.901
	2		363	2-14	37	54	F-1	11	13	236.437
	3		385	2-22	7	8	F-4	1	2†	0†
1334	1	9	150	4-30	27	46	C-4	15	4	33.097
1374	1	18	1282	4-12	80	117	G-4	5	4	26.121
	2		735	3-12	61	115	F-3	21	27	242.576
1386	1	17	395	4-38	24	139	F-4	45	106	861.253
1394	1	12	477	1-27	74	77	C-4	12	12	226.083
1408	1	11	123	2-27	12	10	B-1	3	6	81.031
1410	1	32	386	2-31	60	72	F-1	25	20	230.763
1416	1	22	328	1-34	22	24	A-3	13	19	117.821
	2		689	1-36	69	79	A-1	3	24	111.901
	3		358	2-37	18	27	E-2	3	6	91.534
1418	1	16	59	1-28	10	17	H-4	11	17	108.747
	2		90	1-27	22	28	C-3	1	5	41.808
1422	1	25	92	4-31	11	24	B-4	10	14	234.968
1462	1	6	127	3-19	38	45	G-2	10	20	98.736

*No faders based on stereoscopic examination of SSU.

†Indicates regression estimate of the ground count (estimate made between photographic acquisition and ground visit).

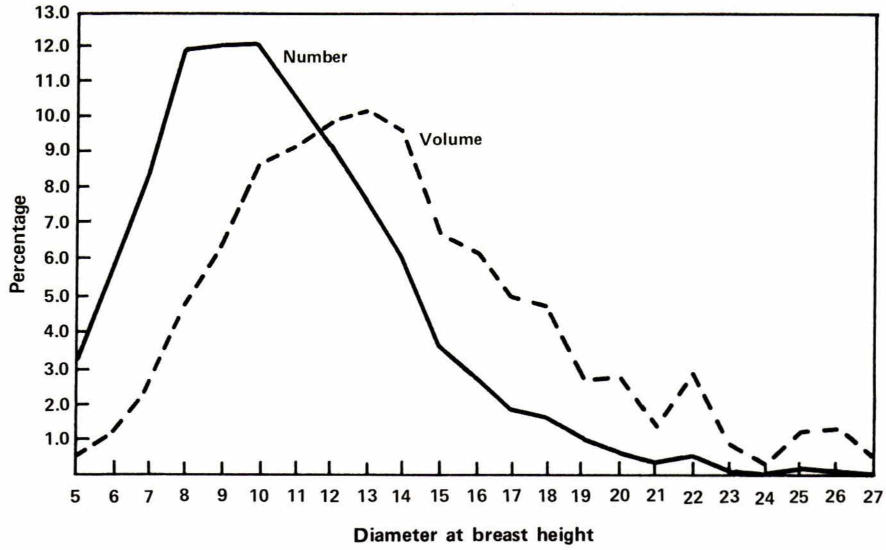

Figure C-1.- Distribution of the number and volume of ponderosa pine faders by diameter class for the Front Range of Colorado (1980).

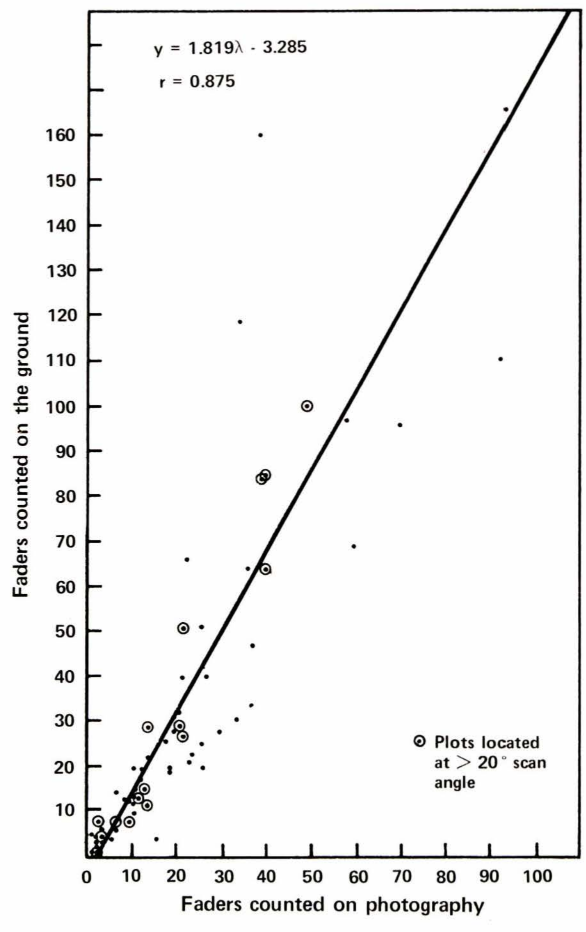

Figure C-2.- Graph of regression estimate of faders counted using aerial photography and those counted on the ground.